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Biostratigraphical investigation of middle-early Miocene sediments from a section of AK-1 well, onshore Niger Delta: Insights from calcareous nannofossils

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Abstract

Biostratigraphic analysis was carried out on KA-1 well, onshore Niger Delta Basin of Nigeria. A total of forty (40) ditch cutting samples were collected from the studied section at 30 feet depth intervals with the studied section ranging from 7590-4800feet. The objectives of this study are to determine the age and biozonation of the studied section. Using simple smear slide method, the samples were processed and analyzed for nannofossils using a reflected binocular microscope. Calcareous nannofossil assemblages from the well are of low diversity and abundance. Some depths yielded almost monospecific assemblages while some have no records of calcareous nannofossils. Species include *Helicospharea ampliaperta*, *Sphenolithus heteromorphus*, *Cyclicargolithus floridanus*, *Helicospharea scissura* and *Discoaster deflander*. These belong to the NN4 zone of middle to early Miocene age.

Keywords: *Biozonation, Calcareous nannofossils, Helicospharea ampliaperta, Oligotrophic, Niger Delta.*

Introduction

The Tertiary Niger delta basin (Fig. 1) is situated along part of the Gulf of Guinea on the west coast of Africa in Nigeria. The Niger Delta is framed on the northwest by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif (Murat, 1972). The Cenozoic Niger Delta occupies an area that is over 256,000 km^2 and sediment fill of about 500,000 km^3. This Niger Delta clastic wedge is about 12 km thick and contains the 12th largest known accumulation of recoverable hydrocarbons, with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas (Tuttle *et al*., 1999). These deposits show an overall upward transition from the basal Paleocene to Recent pro-delta facies of the Akata Formation through Eocene to Recent, paralic facies of the Agbada Formation to Oligocene-Recent and fluvial facies of the Benin Formation (Evamy *et al*., 1978; Short & Stauble, 1967; Whiteman, 1982). These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin.

The Niger Delta grossly consists of three subsurface lithostratigraphic units; the marine Akata Shale, the paralic Agbada Formation and the Benin Sands. The outcropping correlatives

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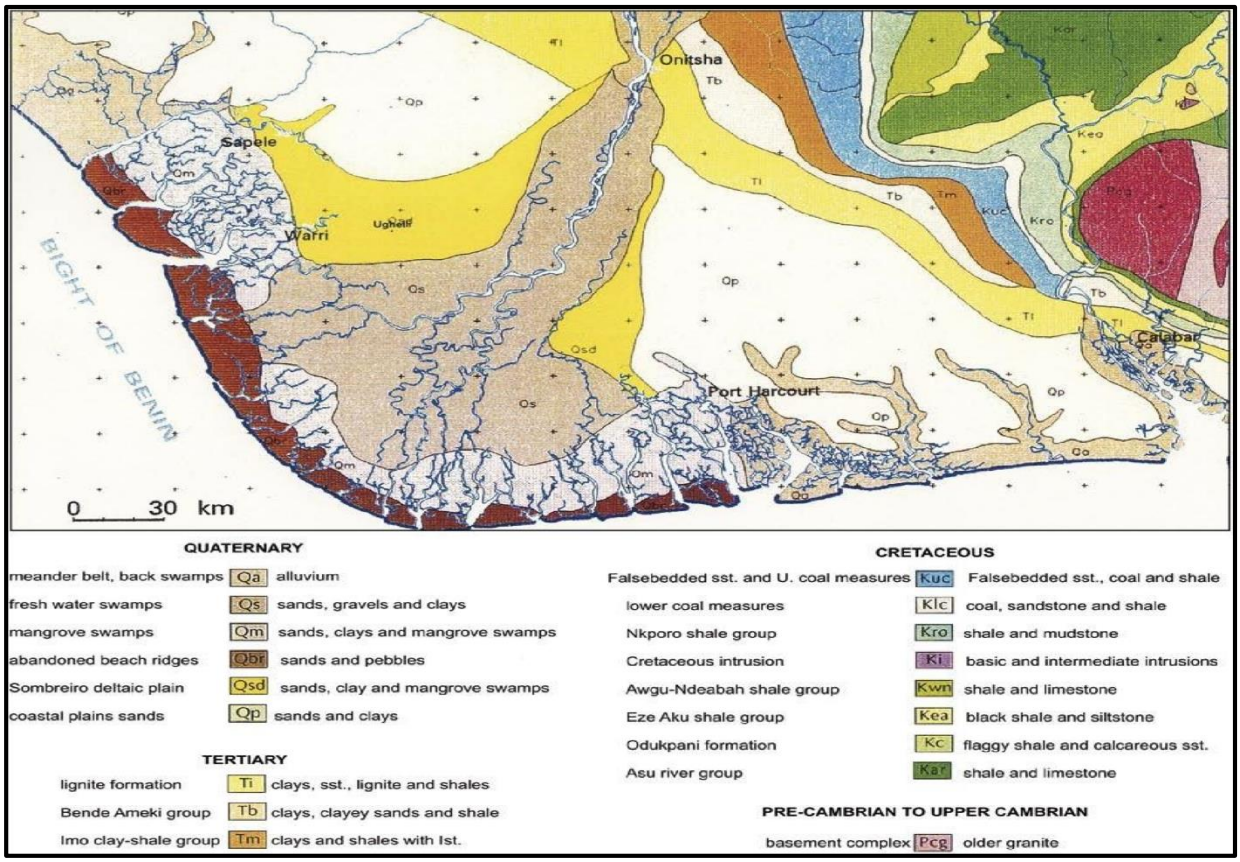

Fig 1: Geological map of the Niger Delta and surroundings (Adopted from Reijers, 2011).

are respectively the Imo Shale, Ameki Group and Benin Sands. The most important and best studied of these is the petroliferous Agbada Formation with its varied lithofacies associations that range from reservoir sands through heteroliths to mudrock seal facies.

Many workers have done extensive biostratigraphical, paleoenvironmental and geochemical studies of the Niger Delta sedimentary successions for petroleum exploration and exploitation, but are hidden on the shelves of oil majors as proprietary materials. The petroleum geology of the Niger Delta has been discussed and described by a few numbers of researchers (i.e., Tuttle *et al*.,1999; Doust and Omatsola 1990; Evamy *et al*., 1978; Weber and Daukoru 1975; Short & Stauble,1967). The use of biostratigraphy tools such as foraminifera, pollen and spores, and calcareous nannofossils in the Niger Delta to delineate sedimentary strata in terms of age and structural relationships have been on the increase over the years (e.g., Fajemila, 2012; Alkali *et al*., 2014: Fajemila & Salami, 2014; Fadiya *et al*., 2014; Adekola *et al*., 2014; Ola, 2018; Fajemila *et al*., 2022; Olayiwola *et al*., 2022; Fajemila *et al*., 2023). Fadiya (1999) identified 28 planktic, 72 benthic foraminiferal species and 33 calcareous nannofossil species from integrated studies of the sediments penetrated by Opolo-5 and Opolo-9 Wells, onshore, western Niger Delta. Two informal planktic foraminiferal zones were established (*Globigerinoides obliquus* and *G. ruber*). These corresponded to the N17 - N19. He assigned a Late Miocene to Early Pliocene age to the studied sequence of both wells on the basis of the foraminiferal zones and the calcareous nannofossil assemblage. Chukwu *et al*. (2012) studied the paleoenvironment of depositions of the Oloibiri-1 well in the eastern Niger Delta and inferred littoral (deltaic) to marine environments on the basis of the occurrence of environmentally restricted taxa,

some of which belong to the following general: *Quinqueloculina*, *Hopkinsina*, *Spiroplectamina*, *Lenticulina*, *Heterolepa*, *Alveolophragmium* and *Textularia*.

Calcareous nannofossils, an aspect of biostratigraphy came up recently in Nigeria and has since gained some ground because of its precise ages, fewer species and universality. Over a decade ago, Boboye & Fowora (2007) carried out calcareous nannofossil biostratigraphic studies on sediments from well XH-1 located in the Deep Offshore of Niger Delta and they recognized two major zones (NN11 and NN10) of late Miocene age. Three nannofossil zones were encountered in their study and they include*: Discoaster quinqueramus zone*, *Discoaster berggrenii zone* and *Discoaster bollii* zone. Nannofossil abundance/diversity pattern revealed three (3) condensed sections associated with 5.8Ma, 7.0Ma and 9.2Ma Maximum Flooding Surface. Similarly, Fajemila & Salami (2014) worked on 226 ditch cuttings samples from two wells in the western Niger Delta. Four biozones, NN12, NN11, NN10 and NN9 were erected based on first and last occurrences of marker species (e.g., *Discoaster quinqueramus*, *Discoaster berggrenii*, *Discoaster braarudii*, *Discoaster pentaradiatus*, *Sphenolithus abies*, *Coccolithus pelagicus*, *Catinaster mexicanus*) as well as their relative abundances. Fadiya (2008) subdivided five major nannofossil zones (NN1, NN2, NN4, NN5 and NN11) in the offshore Niger Delta into subzones based on FOs and LOs of marker species. He was able to correlate the subzones across eight wells located in the different fields in the offshore Niger Delta.

Therefore, the objectives of this study are to attempt a taxonomic identification of calcareous nannofossils encountered in the well; to carry out a nannofossil biozonation of the well interval; to determine the age of the strata penetrated by the well and to attempt a paleoenvironmental determination of the well section based on associated meiofaunas.

Methodology

Samples preparation for calcareous nannofossils and lithological analysis

Forty (40) ditch cutting samples from the depth range of 7590 to 4800 feet of the AK-1 well were prepared in the laboratory and analyzed at 30feet depth intervals. The ditch cutting samples were provided by Chevron Nigeria Limited, through the Department of Petroleum Resources (DPR). The precise name and location of AK-1 well were considered proprietary, and therefore were not given. The Simple smear slide method was routinely applied to process all the samples. Small portion of the sediment was scrapped onto a glass microscope slide with a drop of distilled water and make a thick sediment suspension. Using a flat tooth pick, the suspension was smeared thinly across the surface of the glass slide and placed on a hotplate to dry rapidly. The cover-slip was fixed onto it using two blobs of Norland Optical Adhesive, which was then cured over ultraviolet light for 5-10 minutes. Absolute care was taken at all stages to avoid contamination. The slide was then inspected under a transmitting light microscope in polarised light. For this, a binocular microscope was used with work being done at 1250x magnification with immersion oil. Then standard counts of minimum 12 traverses were carried out followed by an extensive search of the slide for rare marker fossils. This method was standardised for each slide in the AK-1 well. The identification of calcareous nannofossils follows the work of Bown & Young (1998). The data were processed using the Stratabug software (version 1.7). Sawtooth plots of the abundance and species diversity were made from which candidate Maximum Flooding Surfaces were selected.

A detailed vertical lithologic description of the studied ditch cuttings samples was also done. The lithologic description, was based on sedimentological studies and the gamma ray log patterns, since high and low values of delineate shale and sand lithologies, respectively. Essential parameters such as grain size, textures, roundness, color, sphericity, sorting and facies changes were observed and recorded.

Results and Discussion

Lithological analysis

The studied section of the AK-1 well, onshore, Niger Delta covers an interval of 7590 – 4800 feet. Two lithological units (i.e., sandstone and shale) were identified within the studied well interval (Fig. 2). The ditch cuttings and the gamma-ray log revealed an alternation of sand and shale horizons (Fig. 4) that are typical of regressive and transgressive sequences of the Agbada Formation in the Niger Delta (Weber & Daukoru, 1975; Fajemila, 2012; Fajemila *et al*., 2022).

Calcareous Nannofossil Diversity and Biozonation

The recovery from the analyzed forty ditch cutting samples from AK-1 well yielded poor abundance and diversity. The highest nannofossil peaks were dated using important marker species such as *Helicospharea ampliaperta*, *Sphenolithus heteromorphus*, *Cyclicargolithus floridanus*, *Helicospharea scissura* and *Discoaster deflandrei* (Fig. 3 and 5). The significant datums, zonal and age determinations and the identified Maximum Flooding Surfaces are shown in Figures 3 and 4. The species encountered in the well are shown in Fig 4 below.

Nannofossil Zones

5160 – **4800** feet

The interval is virtually barren. No calcareous nannofossils were encountered in this interval. The sediments must have been deposited in a coastal deltaic setting. This interval may represent the base of **NN5 zone** of Martini (1971).

6480 – 5160 feet

This interval contains moderately rich and diverse nannofossil assemblages. The flooding surface recognized within this interval in the **NN4 zone** Middle Miocene. The co-occurrence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* at 5160feet marks the 15.20Ma MFS. The maximum flooding surface at 6060 feet represents 16.96Ma MFS (Gradstein *et al*., 2012) based on superposition. Other important species such as *Coccolithus pelagicus*, *Helicosphaera ampliaperta*, *Cyclicargolithus floridanus*, *Sphenolithus heteromorphus* and *Helicosphaera carteri* occur within the zone.

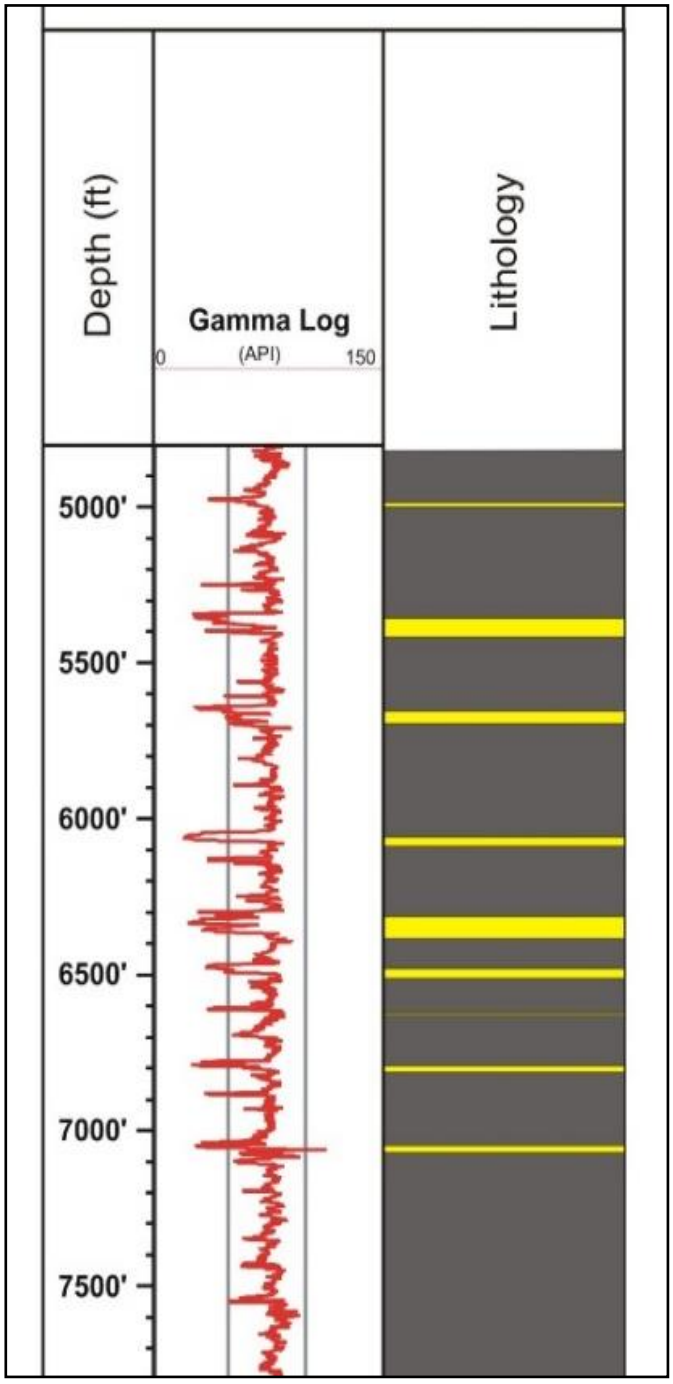

Fig. 2: Lithological characteristics of the AK-1 well, onshore Niger Delta.

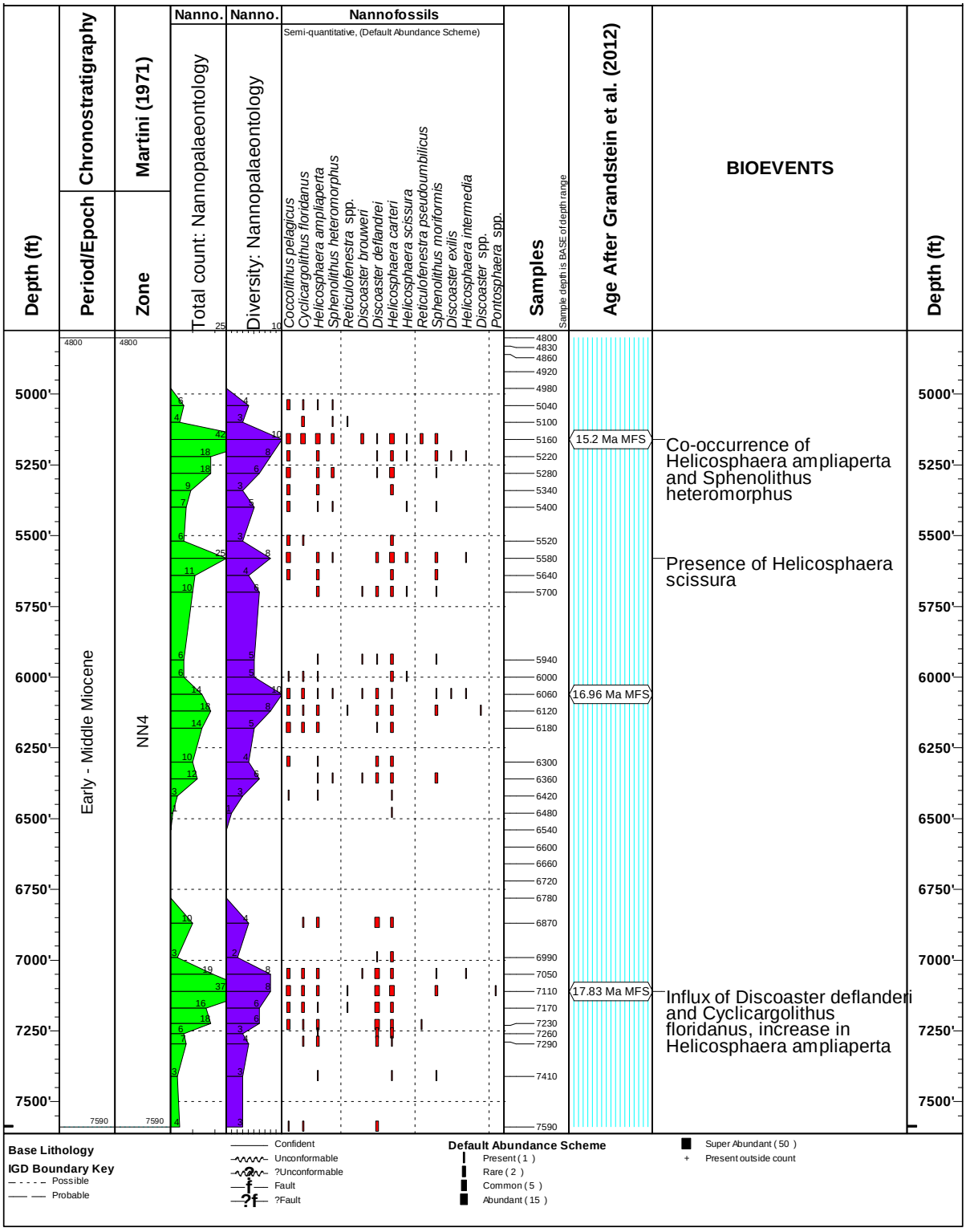

Fig. 3: Stratigraphic distribution of Calcareous Nannofossil in AK-1well.

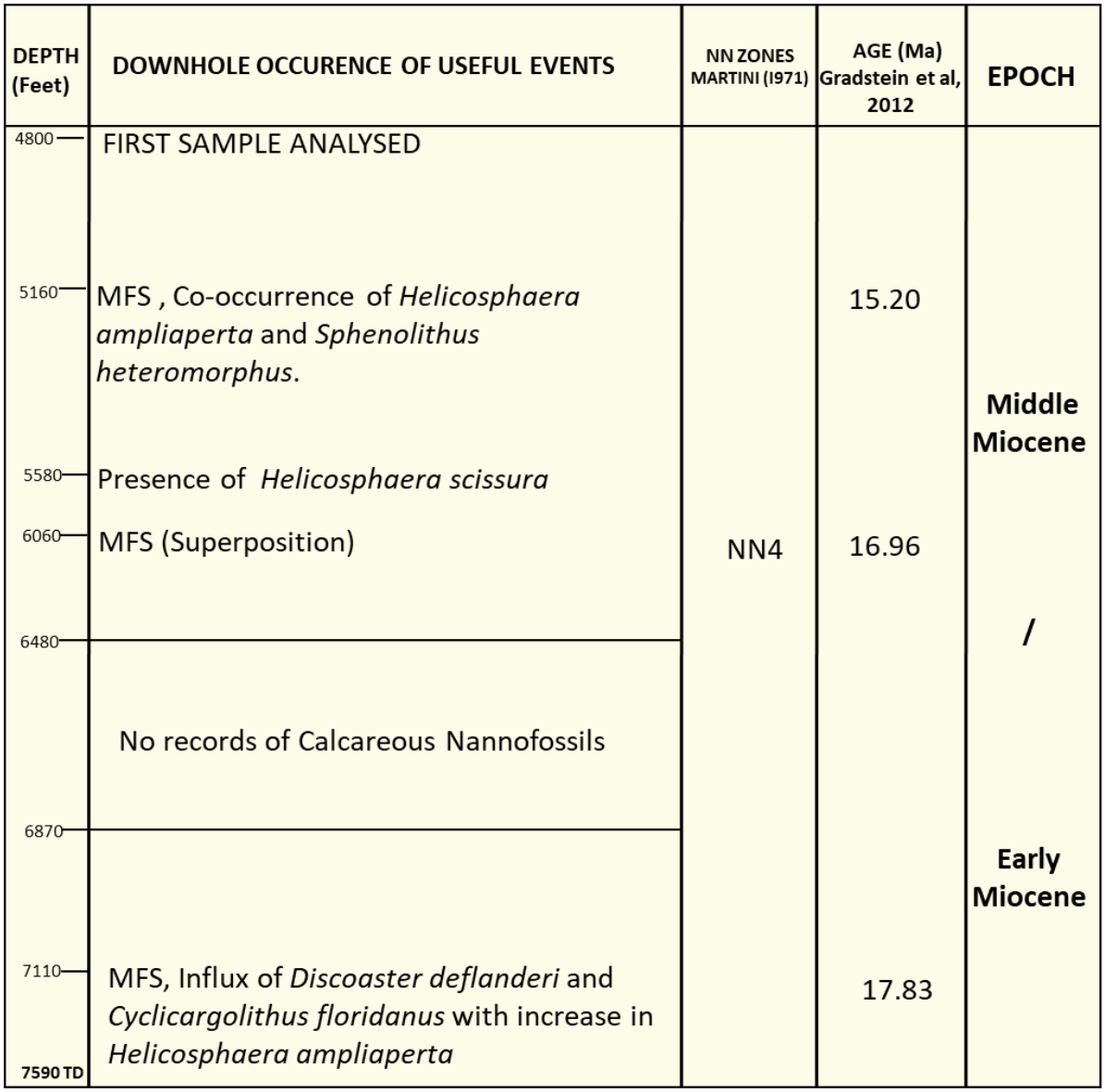

Fig. 4: Calcareous Nannofossil biozonation in AK-1 well

6870 – 6480 feet

No records of calcareous nannofossils in this interval. It is assumed that the interval was deposited in a coastal deltaic environment.

7590 – 6870 feet

This interval is characterized by a well-developed nannofossil abundance and diversity with the highest nannofossil peak at 7110 feet. This peak is considered to represent the 17.83 Ma MFS (Gradstein *et al*., 2012). The increase in the abundant of *Helicosphaera ampliaperta* with the influx of *Discoaster deflanderi* and *Cyclicargolithus floridanus* within this interval indicate the base of NN4 Zone Early Miocene (Martini, 1971). Other important species such as *Coccolithus pelagicus*, *Cyclicargolithus floridanus* and *Helicosphaera carteri* are prominent within the zone.

Calcareous nannofossils in oligotrophic environment

Oligotrophic environments are environments that offers very low levels of nutrients. They are well-lighted environment. Oligotrophs are characterized by slow growth, low rates of metabolism, and generally low population density. Variations in the composition and abundances of taxa are thought to reflect autecological changes, especially of surface

water temperature, nutrients, salinity and detrital input from the continents (e.g., Fajemila *et al*., 2015; Langer *et al*., 2016). Calcareous nannofossils are extensively dispersed and frequently utilized to show short- and long-term palaeoceanographic and paleoclimatic variations in the world's oceans because of their planktonic lifestyle in the upper water column (Adegoke *et al*., 2017).

The rapidly changing and extreme environmental conditions are reflected in abrupt variations in nannofossil assemblages within the AK-1 well. Moreover, the sediments from AK-1 well yielded abundant *Heterostegina* sp., which is a common taxon in oligotrophic environments (Fajemila *et al*. in press). Within the studied section of AK-1 well, heterotrophic foraminiferal species are very rare. *Ammonia* and other opportunistic foraminifera taxa were not present in the well. The assemblage of few calcareous nannofossils species within this environment indicates their tolerance level for well-lighted, oligotrophic environment.

Fajemila & Salami (2014) presented very rich and diverse assemblages of calcareous nannofossils from deep offshore Niger Delta, especially from shaly horizons where there are indications of nutrients availability. These assemblages are different from that of AK-1 well. For example, most species of *Reticulofenestra*, *Discoaster*, and *Calcidiscus* were not recorded. *Coccolithus pelagicus* has proven to be tolerant of low nutrient environment as we have seen in the AK-1 well. Similarly, *Helicosphaera carteri* and *H. ampliaperta* also recorded few to common occurrences within the well. The reduction in the number of taxa is a clear indication of the environment of deposition. This has helped in categorizing these calcareous nannofossil species in the AK-1 well as oligotrophic.

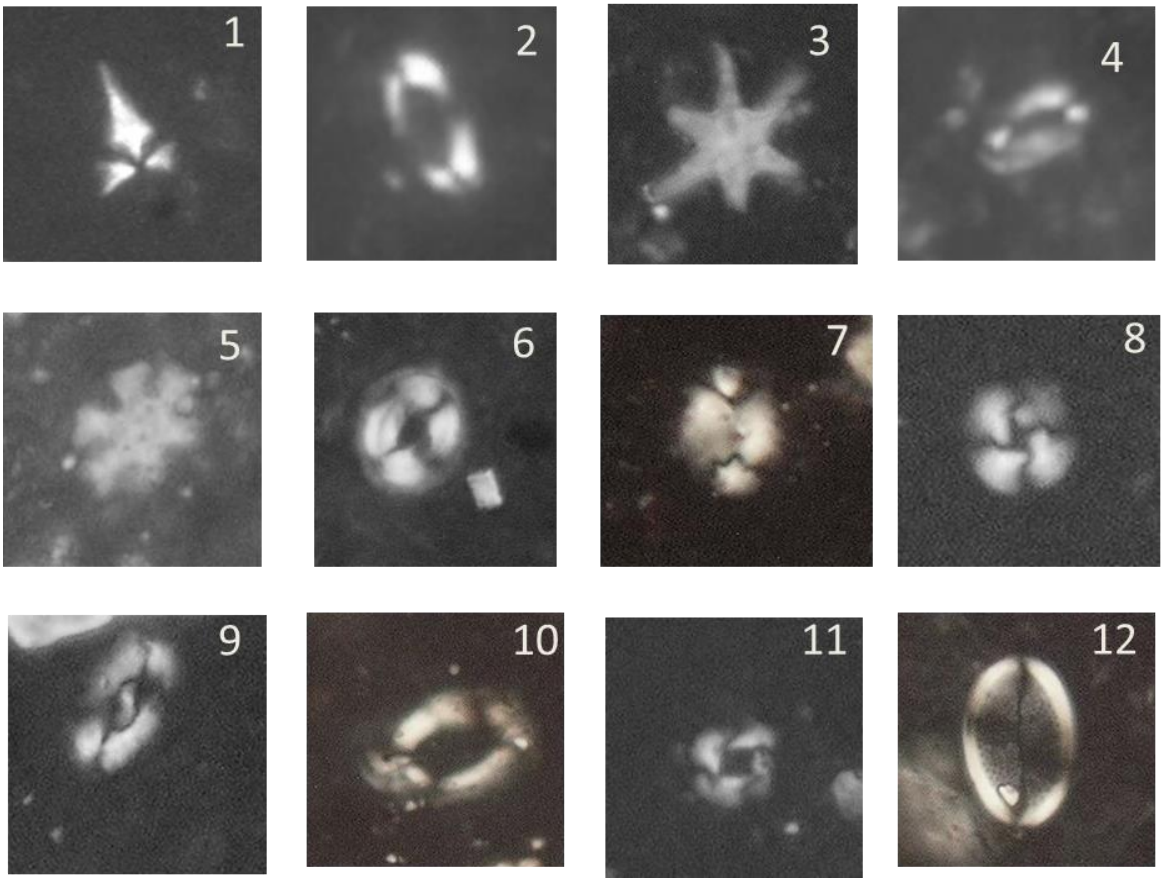

Fig. 5: 1: *Sphenolithus heteromorphus*; 2: *Helicosphaera ampliaperta*; 3: *Discoaster brouweri*; 4: *Helicosphaera scissura*; 5: *Discoaster deflandrei*; 6: *Coccolithus pelagicus*; 7: *Helicosphaera carteri*; 8:

Cyclicargolithus floridanus; 9: *Helicosphaera Reticulofenestra* sp.; 12: *Pontosphaera* sp.

Conclusion

Calcareous nannofossil assemblages from AK-1 well are of low diversity and abundance. The sediments yielded environmentally controlled oligotrophic tolerant species. Some depths yielded few species such as *Helicospharea ampliaperta, Sphenolithus heteromorphus, Cyclicargolithus floridanus, Helicospharea scissura and Discoaster deflander*, while some have no records of calcareous nannofossils. The studied section of the AK-1 well belongs to the NN4 zone of middle to early Miocene age.

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